DEPARTMENT OF DEFENSE

REPORT TO CONGRESSIONAL DEFENSE COMMITTEES
On the Utilization and Demonstration of Fuel Cells

AUGUST 1998

Contents

Preface

The Department of Defense (DOD), like the public sector, continually seeks additional energy-efficient technologies and products to increase operational advantages, to reduce the overall cost of energy use and consumption, and to further enhance our National energy and environmental goals and strategies. DOD depends largely on industry to develop and market many of these technological advances, particularly when the application for the technology resides outside areas considered to be military-unique. However, when requested by Congress to do so, the Department has assisted industry in the evaluation and advanced demonstration of emerging energy technologies to gain their broader acceptance.

Since 1993, the Department, in coordination with the Department of Energy and many others, has facilitated the increased use of fuel cell technology by the Federal government and the public sector. To support and stimulate this objective, Congressionally identified funds have supported DOD components in providing installations, scientific and advanced engineering expertise, and long-term monitoring capabilities. To date, these efforts have decreased the cost of phosphoric acid fuel cells, abated numerous air-emission contaminants, and nurtured the continued competitiveness and future economic viability of fuel cell technology.

Direct planning and oversight for Science and Technology investments is the responsibility of the Director of Defense Research and Engineering (DDR&E). Accordingly, DOD does not require a separate and independent fuel cell S&T program, but will continue to program and budget funds across the services, and to investigate and demonstrate, as necessary, those applications unique and beneficial to the warfighter. The FY98 funds identified by the Committees will be executed jointly by the services and the Department of Energy so that a broader spectrum of interests for this technology is addressed.

Further, to facilitate technology transfer opportunities, the Department for this purpose will continue to participate with industry and other Federal agencies in the biannual seminars on fuel cell technology. The next fuel cell seminar has been planned for November 1998 in Palm Springs, California. The services have developed public information web sites that provide general information and data for this technology area. These sites are listed in Appendix E of the report.

1.0 Introduction

Over several budget cycles, the Department of Defense has received additional funds to support the increased development and use of fuel cell technology and other energy-efficient applications. Subsequently, the conference report to accompany the *National Defense Authorization Act for Fiscal Year 1998,* H.R. Rep. No. 105–340, page 587, requested the Department to report on the development and application of fuel cells. When reporting on the progress, the Department is to address a broader spectrum of interests and application of fuel cell technology within the military departments, and shall incorporate their FY98 plans and strategy and the use of private-sector funds that, at a minimum, equal the Federal funding level for the continuation and development of fuel cell technology. This strategy will continue to avoid duplicate efforts by the DOD and the Department of Energy in this technology area, and will convey a collective and common strategy for future investment in fuel cell technology.

The military departments and the Defense Advanced Research Projects Agency (DARPA) have used Congressionally added prior-year Science and Technology (S&T) funds to explore applications for fuel cells and other energy-efficient technologies, both in military environments and where they might find broader use by industry and the public. When applicable, the funds invested have been leveraged with DOD budgeted funds for this technology, further aided by industry contributions (when appropriate) to increase the opportunity for technology transition and commercialization.

The Department continues to plan and coordinate these efforts with the cooperation of other Federal agencies, including the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and the Environmental Protection Agency (EPA). This has encouraged collaborative efforts in fuel cell research and in the study and monitoring of ongoing advanced DOD demonstration sites that have adopted fuel cell technology.

DOD and the other Federal agencies tend to classify fuel cell technology applications into three broad categories: *stationary, mobile,* and *other uses.* Accordingly, this strategy report has been outlined around these categories. The report (1) clarifies prior Federal agency and program investments in these areas; (2) discusses current or pending National and DOD policy for Utility Management and its impact for enhancing the acceptance and use of fuel cell technology; (3) outlines the DOD FY98 investment strategy; and (4) concludes with a summary of the reports key points and activities.

1.1 Technology Description

Alexander Grove invented the fuel cell in 1839. However, this technology was ignored because of the widespread acceptance of combustion technology during the Industrial Revolution. In the mid-1960s, NASA revisited fuel cell technology for use in the U.S. manned space program. Additional details of NASA's involvement with fuel cell technology are presented in Section 2.3.

A fuel cell is an electrochemical device that converts chemical energy into usable electricity and heat without employing combustion as an intermediate step. Fuel cells are similar to batteries in that they produce direct current (DC) power, using an electrochemical process. A fuel cell works on the basic principle that, when hydrogen fuel is oxidized (chemically combined with oxygen), it releases energy. Similar to batteries, fuel cells are electrically connected in stacks to obtain a usable voltage. However, unlike batteries, fuel cells convert the energy from a hydrogen-rich fuel directly into electricity and operate as long as fuel and oxygen are supplied to the cell.

There are several types of fuel cells, distinguished by the type of electrolyte each uses. The physicochemical and thermal-mechanical properties of the materials used in a fuel cell, particularly the electrolyte, determine the practical operating temperature and useful lifetime of each type. Appropriate for terrestrial applications are the phosphoric acid fuel cell (PAFC), polymer electrolyte-membrane fuel cell (PEMFC), molten carbonate fuel cell (MCFC), and solid-oxide fuel cell (SOFC). Table 1 compares these four types. The current status for each type and its major developers are presented in the following paragraphs.

Table 1. Fuel Cell Characteristics

Characteristic	**PAFC**	**PEMFC**	**MCFC**	**SOFC**
Electrolyte	Phosphoric acid	Polymer	Molten carbonate salt	Ceramic
Operating Temperature	375 ° F (190 ° C)	175 ° F (80 ° C)	1200 ° F (650 ° C)	1830 ° F (1000 °C)
Fuels	Hydrogen (H_2) reformate	H_2 reformate	H_2/CO/reformate	H_2/CO_2/CH_4 reformate
Reforming	External	External	External/internal	External/internal
Oxidant	O_2/air	O_2/air	CO_2/O_2/air	O_2/air
Efficiency (HHV)	40–50%	40–50%	50–60%	45–55%

The PAFC, a commercially available fuel cell, is currently used in cogeneration applications *(cogeneration* refers to the simultaneous production of electrical and thermal energy from a single input fuel source), including landfills, hospitals, computer centers, manufacturing facilities, and others. ONSI Corporation of South Windsor, Connecticut, a subsidiary of International Fuel Cells (IFC), has been actively developing and marketing on-site PAFC systems and has a 40-MW/year manufacturing capability. In their PAFC commercialization program, ONSI Corporation offers a 200-kW PAFC power plant for $3,000/kW. More than 150 of these units presently operate worldwide. Their general performance has been outstanding, and the PAFC is being considered as an uninterruptable power supply.

The PEMFC is being developed for both stationary power and transportation applications. PEMFC hardware incorporates a plastic membrane separator that supports two laminated electrode layers. PEMFC technology arguably is in the pre-commercial stage, but many developers are attracted by its projected low cost. PEMFC fuel cells require hydrogen fuel, so most electricity-production systems include an integrated fuel-processing component. PEMFC's were first developed by the General Electric Company for early NASA projects and flew in the Gemini Program, among others. More recently, they have been developed for submarine propulsion by Siemens (Germany), and for transportation technology by Ballard (Canada). Other contemporary PEMFC developers include, by country: Germany — Daimler-Benz; Italy — DeNora; Japan — Fuji, Mitsubishi, Toshiba, and Toyota; and U.S. — General Motors, Allied Signal, United Technologies, Energy Partners, Analytic Power, Mechanical Technology, and H-Power.

The MCFC is a high-temperature fuel cell being developed for stationary power applications. U.S. developers are the Energy Research Corporation (ERC) and M-C Power (MCP). ERC has constructed a manufacturing plant with a capacity of 2–17 MW per year and has a 460-kW test facility in Danbury, Connecticut. MCP has constructed a manufacturing plant with a capacity of 4–12 MW per year and has a 250-kW test facility in Burr Ridge, Illinois. ERC has conducted a 2-MW Product Development Test (PDT) in Santa Clara, California, and MCP has conducted a 250-kW PDT in San Diego, California.

Several SOFC technology configurations are currently under development in the U.S. for possible stationary power, defense, and transportation applications. SOFC technology configurations are solid state and operate over a wide range of temperatures. Westinghouse Electric manufactured and tested several completely packaged and self-contained generators, up to a nominal 25-kW size. A 4-MW/year manufacturing facility currently produces the cells (tubes), bundles, and generators. A 100-kW generator test in the Netherlands is planned during 1998. In addition, several planar SOFC configurations are being developed by the Institute of Gas Technology, Ceramatec, Ztek, Technology Management Incorporated, and Allied Signal Aerospace Corporation.

1.2 Department of Defense (DOD) Uses

This section describes the current uses of fuel cell technology within DOD, divided into subsections on stationary power applications, mobile power applications, and other power applications. Section 3.0 discusses past and present fuel cell programs within DOD. Section 4.3 provides a perspective on future potential applications of fuel cells within DOD.

1.2.1 Stationary Power Applications

DOD stationary power applications of fuel cell technology are those located at DOD fixed facilities. Congressional identified funds in FY93–94 were used for purchase and installation of ONSI Model PC25 200-kW PAFCs at thirty DOD sites (listed in Appendix A). In addition, Naval Air Station (NAS) Miramar served as the host site for a non-DOD-funded demonstration of an MCFC stationary power application. This section discusses the details of the electrical and thermal energy recovery interfaces at these sites. For stationary power applications, these interfaces are the primary parameters that define the application.

The PAFCs in the DOD fleet are configured for one of two different modes of operation: grid-connected and grid-independent. In the grid-connected mode, the power plant is connected to the utility grid, and operates unattended and automatically at a user-selected power level. If out-of-limit conditions occur on the utility grid, the power plant disconnects from the grid and operates in the idle mode. The power plant shuts down if any internal component malfunctions occur. In the grid-connected/grid-independent mode, the power plant is supplied with two sets of output terminals, one connected to the utility grid and the other to a dedicated load.

Under normal operation, the power plant supplies power to the grid, as in the grid-connected mode. If utility power is lost, the power plant will disconnect from the utility grid and supply power to the dedicated load, thus operating as an emergency generator. The fuel cell power output will respond to fluctuations of the dedicated load. When utility power is restored, the power plant will switch between output terminals and return to normal operation, supplying power to the utility grid.

Five DOD sites are using the grid-connected/grid-independent mode of operation, while two others have made provisions to use this mode in the future. Two are providing emergency backup power for galleys, two are providing emergency backup power for boiler plants, and one is providing emergency backup power to a field house facility that is designed to serve as a shelter during emergencies.

All fuel cells in the DOD fleet were installed near a facility or building to take advantage of thermal cogeneration. Therefore, the PAFC’s electrical output was usually directed into the facility’s 480V electrical distribution system through an existing or retrofitted electrical panel. If the facility’s electrical demand falls below 200 kW, the excess power is exported to the utility grid via the facility's distribution transformer.

Thermal energy produced as a byproduct of electric power generation within the DOD fleet has been used in a variety of different cogeneration applications. Thermal storage tanks have been installed where appropriate to maximize utilization of hot water produced during times of low thermal demand. Eleven PAFCs in the DOD fleet have been installed at central heating plants, providing hot water for use as preheat boiler makeup water and/or condensate return. Seven PAFCs are installed at hospitals to provide domestic hot water (DHW) and to supplement space-heating systems and reheat cooling systems. The remaining fuel cells in the fleet are installed at various locations, including barracks, gymnasiums, office buildings, kitchens, and a laundry. Their thermal applications include heating DHW, heating swimming pools, and providing hot water for heating and reheat cooling systems.

Of particular note is the thermal application at Davis-Monthan AFB, which is the first demonstration of an absorption chiller/PAFC application in the U.S. The high-grade thermal output is used to heat three 10-ton absorption chillers, which in turn provide air conditioning to a gymnasium. The low-grade thermal output heats an existing 1,500-gallon DHW storage tank located in the mechanical room.

As noted, NAS Miramar, California was selected to be the host site for the world's first cogeneration application of an MCFC power plant. This power plant was developed by M-C Power Corporation and funded by a consortium consisting of DOE, research organizations, and utility companies. Installed early in 1997, it provided 250 kW to the NAS Miramar electric grid and generated 100-psi steam to supplement the NAS Miramar existing steam-distribution system.

1.2.2 Mobile Power Applications

DOD mobile power applications are those in which fuel cell technology is used for vehicular propulsion. This includes land-based, marine, and aeronautical vehicular propulsion systems. Although not currently using fuel cells in mobile applications, DOD does invest in R&D programs to adapt fuel cell technology to mobile power requirements. Additional information is provided in Sections 3.3 and 4.3.2.

1.2.3 Other Power Applications

Other power applications are neither stationary nor mobile, and include (but are not limited to) portable generators (called Mobile Electric Power generation by the Air Force) and individual-soldier power packs. Although not currently using fuel cells in such applications, DOD has identified and is investigating a number of potential applications other than stationary and mobile for which fuel cell technology appears adaptable to meet DOD requirements. Additional information is provided in Sections 3.4 and 4.3.3.

2.0 Other Federal Participation

While this report has been developed around DOD fuel cell activities, the overall U.S. fuel cell program involves funding from many Federal, state, and private entities. DOE, EPA, and NASA all manage significant Federal fuel cell technology programs. These programs are described in greater detail in the following sections. In addition, the U.S. Departments of Transportation and Commerce, and the DOE Office of Energy Efficiency and Renewable Energy among others, fund a variety of fuel cell programs for commercial transportation and other applications; these program were considered beyond the scope of this report.

2.1 U.S. Department of Energy (DOE)

Fuel cell technology offers an attractive alternative for power generation due to its ultra-high energy-conversion efficiency and extremely low environmental emissions. Thus, DOE supports the development of fuel cell technology for stationary electric power applications. DOE's Federal Energy Technology Center (FETC) continues to sponsor a fuel cell program to develop high-efficiency natural gas-fueled power-generation technologies.

DOE's fuel cell program is market-driven, enjoying over 40% cost-sharing by industry. The agency funds the development of PAFC, MCFC, and SOFC technologies. It also cooperates with DOD and other Federal agencies to leverage additional funds to enhance fuel cell technology development. DOE's support of PAFC has been completed, and development of MCFC and SOFC is planned to continue at comparable funding through 2002, the planned commercialization date for these technologies

Fuel cells can be used for a wide variety of power plant applications operating on a variety of fuels in a range of power-generation capabilities ranging from kilowatts to hundreds of megawatts. However, it is likely that their primary application for the foreseeable future will be as distributed-generation (DG) technology. DG technologies, including fuel cells, still require development. It is likely that this development will occur rapidly, given the expansion in the DG market anticipated during deregulation of the U. S. electric power industry.

The major drawback to widespread acceptability of fuel cell technology is its relatively large initial capital cost in comparison to other electric-generation technologies. It has been estimated that a 50% reduction in initial capital cost will be required to make fuel cell technology economically viable for widespread use. This cost reduction can be brought about by increased production, which takes advantage of economies of scale, and by R&D efforts that lead to lower cost for individual components. DOE has participated in a variety of programs that directly support both methods of cost reduction.

2.2 U.S. Environmental Protection Agency (EPA)

EPA and FETC are cosponsoring the demonstration of a Westinghouse 1.3-MW tubular solid-oxide fuel cell at an EPA Laboratory at Fort Meade, MD. This demonstration will permit assessment of environmental emissions and electrical performance for this technology. The demonstration is an integral part of the DOE/Westinghouse development and demonstration program. Construction is scheduled to begin during 1998–1999.

2.3 National Aeronautics and Space Administration (NASA)

In the early years of U.S. space flight, the fuel cell was selected over competing power systems for its greater promise to meet the on-board requirements of NASA's extended-duration manned missions. In addition to satisfying on-board requirements, the fuel cell offered special advantages over competing power systems, most noteworthy being its ability to operate on pure hydrogen and oxygen and to supply potable water (as a byproduct of the electrochemical reaction) for crew consumption and for cabin humidification.

General Electric 1-kW fuel cells were used for seven flights in the Gemini Earth-orbiting program (1962–1965). These fuel cells were of the ion-exchange membrane type (IEM) and were the precursors of the modern PEMFC (polymer electrolyte-membrane fuel cell). Higher-performance Pratt & Whitney 1.5-kW alkali fuel cells were used in later Apollo missions (1968–1972). The present Space Shuttle Orbiter is equipped with three alkali fuel cell power plants from United Technologies Corporation that supply 12 kW peak power and 7 kW average power. The orbiter's fuel cell power plants are 50 pounds lighter and deliver up to eight times as much power as those of Apollo.

NASA's plans for future exploration of the Solar System include establishment of manned outposts as well as central base stations on the Moon and Mars. Because the solar-based surface power system on the Moon or Mars must supply usable power continuously — that is, during nighttime as well as daytime — a regenerative system is required. In a Lunar application, the period of darkness extends 2 weeks, whereas a Martian application presents a more manageable 12-hour night.

In both cases, a regenerative fuel cell (RFC) system (consisting of an electrolyzer–fuel cell combination) is enabling; even advanced batteries are far too heavy, especially for the Lunar day-night cycle. In a regenerative fuel cell system, solar energy is used to power the station during the day and to generate hydrogen and oxygen from water. The hydrogen and oxygen thus generated are then used in a fuel cell to generate power at night. The RFC–Lunar/Mars Project is being managed by the fuel cell team at NASA's Lewis Research Center (LeRC).

NASA's Jet Propulsion Laboratory (JPL) is currently testing an advanced PEMFC stack, operating on both pure oxygen and mixtures of oxygen and nitrogen, as part of the NASA Shuttle Orbiter Fuel Cell Upgrade Project. The goal of this testing is to replace the present Shuttle Orbiter alkaline fuel cell power plant with an advanced PEMFC power plant. This will provide greater power, increased safety, increased mission capability, and longer mission life, all at significantly lower capital cost. A PEMFC stack developed by International Fuel Cells Corporation (IFC) is currently under evaluation at LeRC.

In addition, NASA has recently begun a new program to develop the Reusable Launch Vehicle (RLV), the proposed successor to the Shuttle Orbiter. In this new program, NASA and its contractors are developing a PEMFC power plant to provide onboard power to the vehicle. On a lesser scale, NASA is developing a PEMFC power plant to allow longer mission duration for unmanned high-altitude-balloon science missions.

3.0 Department of Defense (DOD)-Sponsored Programs

3.1 Overview

This section describes past and current fuel cell technology programs that were funded in whole or in part by DOD. Subsections describe stationary power application, mobile power application, and other applications.

3.2 Stationary Power Applications

DOD has funded three major efforts involving fuel cell technology for stationary power applications: (1) The Natural Gas Utilization Equipment Program (commonly called the DOD Fuel Cell Demonstration Program), funded in FY93–94, provided for purchase and installation of PAFC power plants on DOD facilities. (2) The Climate Change Fuel Cell Program (commonly called the DOD Fuel Cell Rebate Program), funded in FY95–97, provided Federal grants to non-Federal entities that purchased and installed PAFC power plants, with priority to those installed on DOD facilities. (3) The Navy Environmental Quality Program, funded in FY98, provided funds for a cost-shared demonstration of PEMFC technology at the Naval Surface Warfare Center in Crane, Indiana. Each of these programs is described below.

3.2.1 Natural Gas Utilization Equipment Program

In FY93, Congress identified $24M for natural gas utilization equipment, of which $18M was designated for procurement of natural gas fuel cells for power generation at military installations.[1] This funding resulted in procurement and installation on DOD facilities of one Model PC25A and eleven Model PC25B fuel cell power plants manufactured by the ONSI Corporation (a subsidiary of International Fuel Cells).

In FY94, Congress identified $30M for natural gas utilization equipment, of which $17.8M was designated for continued procurement of 200-kW phosphoric acid natural gas fuel cells.[2] [3] This funding resulted in the procurement and installation on DOD facilities of three Model PC25B and fifteen Model PC25C fuel cell power plants manufactured by the ONSI Corporation.

The purchase, installation, and ongoing monitoring of the thirty fuel cells provided by FY93–94 appropriations has come to be known as the DOD Fuel Cell Demonstration Program. PAFC technology matured through this program, as evidenced by the progression from the Model PC25A (the first commercial fuel cell), to the more advanced Model PC25B, and now to the Model PC25C, the current commercial model. Estimated savings as of December 1997 exceeded $1.2M on purchased electricity costs and thermal energy displaced by fuel cell waste heat recovery, based on monitoring of the thirty fuel cells in the DOD fleet. This has been achieved

with essentially zero emissions of carbon monoxide (CO), nitrogen oxides (NO_x), and sulfur oxides (SO_x) and with a reduction of approximately 50% of the emissions of carbon dioxide (CO_2) associated with conventional power-generation technologies.
Additional savings have been realized at a number of DOD sites in the form of avoided costs, such as the ability to shut down a highly inefficient boiler, avoidance of fines resulting from violation of air emission limits, and cancellation of previously planned procurement of backup generation equipment. Further discussion of the environmental benefits associated with fuel cell power plants is in Section 5.0. A list of the thirty DOD sites where these fuel cells have been installed is in Appendix A.

3.2.2 Climate Change Fuel Cell Program

Congress identified funds in FY95–97 for Federal grants of $1,000/kW to non-Federal entities that purchased and installed PAFC power plants, with priority to those installed at DOD facilities. The intent was to reduce fuel cell initial capital cost by increasing production to provide economies of scale. FY95 funding was $8M and the FY96–97 combined funding was $10.6M. All grants awarded under this program were for purchase of ONSI 200-kW Model PC25C PAFC power plants, the only commercially available fuel cell power plant available at the time. Thus, each grant was for $200,000.

DOE assisted DOD in implementing the FY95 Climate Change Fuel Cell Program. FETC facilitated a multi-agency team to evaluate and prioritize applicant proposals for selection of Federal grant awardees. More than thirty awards have been made to date, and more than fifteen have proceeded through acceptance testing. It is anticipated that ten additional awards will proceed through acceptance testing during calendar year 1998.

The combined FY96–97 Climate Change Fuel Cell Program was managed by the U.S. Army's Armament Research Development & Engineering Center (ARDEC). This resulted in 167 applicants requesting a total of 460 fuel cells. As in the FY95 program, a multi-agency team was assembled to evaluate and prioritize applicant proposals for selection of Federal grant awardees. The FY96–97 program resulted in the award of 53 Federal grants.

3.2.3 Navy Environmental Quality and Logistics Program

Congress identified $1.75M in FY98 to establish a cooperative R&D effort between the Naval Surface Warfare Center (NSWC) in Crane, Indiana and private industry for a cost-shared demonstration of proton-exchange membrane fuel cell technology.[4] The team assembled for this program includes the NSWC Crane Power System Department (host site), Cinergy Technology, Inc. (which purchased the fuel cell and is sharing half the program cost), Ballard Generation Systems Corporation (manufacturer of the fuel cell), and Indiana University (to assist in analysis of performance data). This project, which began in March 1998, will provide the first test and evaluation of a 250-kW PEMFC stationary power plant outside a Ballard facility. Installation of the fuel cell is scheduled for June 1999, with analysis scheduled to end in September 2000.

3.3 Mobile Power Applications

The Army's Tank Automotive Command (TACOM) National Automotive Center (NAC) is investigating the adaptation of fuel cells to replace existing diesel engine systems in military land-based vehicles. Use of fuel cells would result in increased range and enhanced stealth missions due to the inherent high efficiency and quiet operation. TACOM has planned three efforts, including the High Mobility Multi-Mission Wheeled Vehicle (HMMMWV), medium truck, and line haul tractor demonstrations.

The Navy is investigating the suitability of fuel cells as a power source for ship service power and/or main propulsion. This work is being performed by a Federal interagency working group chartered by a Memorandum of Understanding entitled "Fuel Cell Technology Development for Marine Applications." This working group was formed to raise awareness of fuel cell benefits within the marine community and to share research resources through a coordinated plan. Member agencies include the U.S. Coast Guard, Maritime Administration, Research and Special Programs Administration, Naval Sea Systems Command, Office of Naval Research, National Oceanic and Atmospheric Administration (NOAA), and FETC.

The challenge of adapting fuel cells for Navy ship application is daunting. Naval ships will require the reformation of diesel fuel into hydrogen gas, a technology that is still quite immature for the megawatt levels needed on ships. Diesel fuel is very difficult to reform due to its chemical nature, which promotes soot and tar formation, fouls catalysts and heat exchangers, and eventually can deactivate reforming and fuel cell catalysts.

In addition, power control under changing load conditions creates a unique safety challenge for the Navy. While the fuel cell itself will react to changing load demands, excess hydrogen is produced under a rapid load shedding scenario. This would require the safe removal of hydrogen in order to alleviate buildup in the ship's engine room.

Fuel cells aboard ships must operate without performance degradation when subjected to extreme motion. Also, shipboard vibration, which can become extreme under combat conditions, may adversely affect fuel cell performance. In addition, ships operate in extreme environments of salt corrosion, temperature, and humidity.

The Navy's technical approach is to adapt existing fuel cell technology to operate in the harsh marine environment. This involves (1) development of computer simulations of various fuel cell technologies modified for marine service, (2) quantification of potential payoffs by means of ship impact studies, (3) demonstration of diesel fuel processing techniques, and (4) demonstration of small-scale hardware to verify the models. Specific efforts include (1) demonstration of a 10-kW autothermal diesel fuel reformer (ATR) with efficiencies of 71–74%, (2) operation of a 25-cell PEMFC stack on simulated reformer effluent, (3) investigation of a 500-Watt sulfur-tolerant SOFC system operating on diesel fuel, and (4) a study to determine the need for improved methods of salt removal from the air intakes of shipboard gas turbines for operating fuel cells in a marine environment.

The Office of Naval Research, in cooperation with the Naval Sea Systems Command, initiated a three-phase advanced development program in FY98 to demonstrate that commercially developed fuel cell technology can operate on naval logistics fuel in a marine environment. Phase I of this program will (1) perform a conceptual design of a 2.5-MW ship service fuel cell (SSFC) power plant, capable of operating on naval logistics fuel, containing 1% sulfur by weight; (2) demonstrate critical components or subsystems (e.g., a full-size unit cell, contaminant removal system, etc.); (3) perform tradeoff studies to determine the optimum fuel cell stack, support system, and power-conditioning requirements to meet specified voltage requirements; (4) perform shock and vibration tests on selected cells; and (5) demonstrate that the SSFC can operate in a salt-air environment.

Phase II will (1) design and build a 0.5-MW reduced-scale demonstration SSFC; (2) perform land-based tests to demonstrate that the SSFC meets ship service requirements; and (3) deliver the demonstrated 0.5-MW reduced-scale SSFC to the Navy for at-sea testing.

Phase III will demonstrate that a diesel-fed fuel cell can effectively operate in an at-sea environment and meet ship service power requirements.

3.4 Other Power Applications

DOD relies heavily on mobile, air-deployable infrastructure elements, including Mobile Electric Power (MEP) generators, to stage and support U.S. air and land operations around the globe. The Air Force is investigating the use of fuel cell technology as a replacement for existing logistics-fueled MEP generators to provide efficient, reliable, and environmentally safe electric power to bare-base and Air Expeditionary Force (AEF) operations. These efforts have been directed toward developing a logistics-fuel reformer suitable for mobility operations.

The U.S. Army Wide Area Mines (WAM) Program is evaluating the potential use of PEMFCs operating on methanol to replace the batteries they currently use. A production prototype for further evaluation by WAM is anticipated in the near future.[5] Additional DOD efforts in the "Other Power Applications" category are discussed in the following section.

3.5 Department of Defense Advanced Research Projects Agency (DARPA)

In FY94, Congress identified for DARPA approximately $11.4M for fuel cell technology, of which $1.25M was identified for further development of 200-kW phosphoric acid fuel cells. This work was to be conducted under the auspices of the U. S. Army Construction Engineering Research Laboratories (USACERL).[6] The funds provided to USACERL were used to fund a research proposal submitted by International Fuel Cells, entitled “Improvement and Cost Reduction of PC25 Natural Gas Phosphoric Acid Fuel Cell Power Plant.” This effort resulted in development of several improved, lower-cost fuel cell power plant components that have been incorporated into the ONSI production program, and which have been retrofitted into existing fuel cell power plants.

The cost of the PC25 PAFC power plant was reduced from $1.1M when purchased in the FY93 Demonstration Program to $637K when purchased in the FY94 Demonstration Program. This cost reduction was due in part to this effort and to the economies of scale achieved by increased production (resulting from the procurement of the thirty PAFCs in the DOD Fuel Cell Demonstration Program), as well as other independent efforts by IFC.

In addition, DARPA and FETC have worked together to develop a test simulator for MCFC power plant subsystems. This collaboration was aided by the development of an Interagency Agreement to address new or future coordination requirements between the DARPA and DOE fuel cell programs.

The Department of Defense procures, maintains, and upgrades a family of diesel-fueled mobile field generators and auxiliary power units. These generators are considered unreliable for critical standby power applications. They also have many improvement needs, such as excessive noise, relatively high emissions of air pollutants, relatively low efficiency (particularly at partial load), and frequent maintenance requirements.

Fuel cell technology that is currently being developed for commercial stationary power and transportation applications has the potential to alleviate many of these problems. However, commercial efforts are focused on the use of natural gas and methanol, rather than the heavy hydrocarbon liquid fuels required by the military services. Reforming these heavy liquids into a fuel gas suitable for oxidation in today’s fuel cells requires higher operating temperatures than methane or methanol reforming, and requires the handling or removal of impurities such as sulfur. Therefore, DARPA has funded a program to develop reformer technology for multikilowatt fuel cell systems for military applications that is capable of operating on logistics fuels (such as DF-2 or JP-8).

In addition to reformer technology development, planar solid-oxide fuel cell technology has been supported by DARPA because it promises very high specific power and a tolerance to sulfur and carbon monoxide. These contaminants are often found in the output stream of logistics-fuel reformers and will poison fuel cells that operate at lower temperatures.

These R&D efforts are culminating in three demonstrations in FY98: (1) an adiabatic reformer that can be configured to supply enough reformate for a 100-kW fuel cell system, (2) a 20-kW unmixed reformer that offers the potential for highly compact systems, and (3) a 10-kW partial oxidation reformer that will be integrated with a planar solid-oxide fuel cell stack.

DARPA has investigated the feasibility of using a portable fuel cell (less than 500 watts) to replace/augment existing battery packs for individual-soldier use. The use of fuel cells to power in-field communication equipment, sensor suites, and battery chargers would result in effective weight-savings and a longer lifetime over the current use of batteries. The technical challenge of portable fuel cells continues to be development of a hydrogen source for the fuel cell. Small fuel cell systems are likely to be cost-effective only if the hydrogen is obtained from a source other than reforming diesel fuel. However, larger fuel cells (greater than 500 watts) will continue to depend on hydrogen reformed from diesel fuel.

4.0 DOD Utility Management Strategy

4.1 National Perspective

Americans share a desire for a high quality of life, characterized by good health, prosperity, security, and a clean environment. Government seeks to create conditions where these shared desires have the greatest chance of being realized. Good energy policy is an enabler for each of these facets of the American dream. It is no exaggeration to say that energy is the lifeblood of the modern economy. In the past five years, the Clinton Administration's energy policy has provided substantial economic, environmental, and National security benefits to the American public. However, this policy has been based on a legislative and regulatory framework last revised in the early 1990s.

In the context of a market-based energy policy, the Comprehensive National Energy Strategy proposes five specific goals for the Nation. These goals are (1) to improve energy efficiency, (2) to ensure reliability, (3) to promote clean energy technologies, (4) to expand future energy choices, and (5) to cooperate internationally on energy issues. Fuel cell technology, with its positive attributes of increased efficiency, high reliability, low emissions, and international interest, is consistent with each of the National Energy Strategy goals and implementing strategies.

4.2 DOD Reform Initiative for Privatizing Utility Systems

DOD has historically been subject to regulatory requirements that mandate procurement from specific electricity suppliers. Like other large consumers of electricity, DOD expects savings from deregulation and restructuring in the industry. The extent of these savings is difficult to quantify. Studies by the EXETER Corporation indicate potential savings of 3–5%, while other studies, like the GAO Audit of Defense Facilities, are more optimistic. All forecasts are speculative at best, and all are subject to a number of variables outside the control and influence of DOD. Some of the more significant variables are the rate and extent of restructuring and the extent to which DOD can aggregate loads and procurement of electricity. The aggregation of loads will affect load profiles, peak demands, and other variables that significantly affect cost. Other traditional requirements, such as quantity and quality of electricity, time-of-day usage, and reliability, will continue to be important factors.

The Defense Reform Initiative, as promulgated by the Secretary of Defense in November 1997, indicates that by January 1, 2000 DOD will privatize all utility systems (electrical, water, wastewater, and natural gas) except those needed for unique security reasons or when privatization is uneconomical. Most of the Department's utility systems are old and need significant repair. The funding required to modernize these systems would exceed the

Department's current and anticipated resources for these activities. Local utilities and other entities, by contrast, do have the resources to invest in these systems and the expertise to maintain them appropriately.

At this time, DOD is embarking on an ambitious program to transfer ownership, operation, and maintenance of its utility systems, dependent on life-cycle economics and mission-readiness. As of December 31, 1997 privatization has been achieved for 25 systems, and 45 are in process. The Services have begun studies of another 150 systems, with some 500 remaining for review.

In the past, progress in privatizing utilities has been slow because the Department was obliged to seek special approval from Congress for each transaction with the private sector. To speed the process and capture the benefits of privatization, DOD proposed and Congress recently approved the broad authority to expedite utility privatization.

DOD spends over $2.2 billion per year on energy facilities. This large buying power gives DOD great potential market leverage. By shedding utility infrastructure, DOD energy managers can focus on the task of minimizing overall energy cost.

The net impact of these changes will be to lower procurement cost, and the net effect of lower cost will be to change the economics and paybacks of new electric-generation technologies, such as fuel cells. Fuel cells will continue to compete with other readily available alternatives. Many issues — including reliability, peak demand, and electricity cost — will affect the viability, applicability, and potential use of fuel cells. The initial potential applicability of fuel cells for DOD will likely focus on specific, military-unique applications, rather than direct competition with major power marketers or suppliers.

4.3 DOD Perspective on Fuel Cell Utilization

Section 1.2 discussed current applications of fuel cell technology within DOD. Section 3.0 presented past and current programs that apply fuel cell technology within DOD. DOD's experience from these applications and programs indicates that fuel cell technology has the potential to provide great benefit to DOD in a wide variety of applications. Some of these applications are viable at the present time. Other applications will require advances in fuel cell technology, chief among these being multi-unit load-sharing capability, fuel flexibility, and lowered capital costs.

This section discusses applications within DOD for which fuel cell technology holds great promise. As in previous sections, the discussion is divided into stationary power applications, mobile power applications, and other applications. Also included is a discussion of the technology advancements required to render viable applications in each of these areas.

4.3.1 Stationary

Applications that hold the greatest potential for stationary use are cogeneration and premium power generation. Either may be served through DOD ownership of fuel cell power plants or through third-party ownership in the form of shared energy savings or energy service performance contracts. The Climate Change Fuel Cell Program discussed in Section 3.2.2 seems ideally suited for the latter option.

As noted earlier, *cogeneration* refers to the simultaneous production of electrical and thermal energy from a single input fuel source. The electrochemical reactions that occur in a fuel cell power plant produce significant heat that can be recovered in a cogeneration system. Today's natural gas-fueled fuel cell power plants operate with an electric energy conversion efficiency of 40–50%. This figure is predicted to climb to the 50–60% range in the near future. When a fuel cell power plant is operated in the cogeneration mode, overall energy conversion efficiencies (electrical plus thermal) can exceed 85%.

All of the fuel cell power plants installed as part of the DOD Fuel Cell Demonstration Program (Section 1.2.1) employ cogeneration in their day-to-day operations. The largest single thermal energy-recovery application in this program is the preheating of boiler makeup water and/or condensate return at central heating plants of district heating systems. Thermal utilization for this application is consistently high (often 100%), and many of these sites could easily use all of the thermal energy that would be provided by additional fuel cell power plants located at the same central heating plant.

DOD is the largest single owner of district heating systems in the United States. Therefore, this particular thermal recovery application could enjoy widespread use throughout DOD. Further, the DOE's Federal Government Energy Policy recommends expanded use of combined heat and power generation (cogeneration) at Federal facilities.[7] It follows that, where economically feasible, sufficient fuel cell power plants should be employed for cogeneration at central heating plants throughout DOD.

"Premium power applications" are those critical and semi-critical loads that require electric service with a greater quality and reliability than normally is provided by an electric utility. Fuel cell power plants offer the highest reliability and power quality of any electric power-generation technology. In addition, backup generators (such as diesel) and uninterruptable power supply (UPS) systems only operate during a grid outage. As such, they serve no useful purpose while the grid is working properly. Also, backup generators must be relied upon to start promptly, commonly after a long period of non-operation.

Fuel cells, on the other hand, provide continuous power, eliminating nonproductive standby time and uncertainty during emergency startup. Stationary premium power applications within DOD in which fuel cell power plants are perceived to be the power-generation technology of choice include medical treatment facilities, high-security facilities, communications and data centers, DOD advanced manufacturing process facilities, radar sites, DOD research and testing facilities, and remote fixed-facility locations.

The fuel cells used in these applications may operate in the grid-independent or grid-connected/grid-independent configurations. In the former, fuel cells are the primary power provider, with the grid (or other power-generation source) as the emergency backup. In the latter, fuel cells supplement the grid under normal operation and provide backup power in case of grid outage. Where reliability requirements exceed even those associated with a fuel cell (~95%), greater reliability can be attained through the use of additional fuel cells operating in parallel with those required to meet the basic load requirements. In normal operation, these additional fuel cells would provide power to the local grid.

Some of the stationary power applications discussed above are economically viable at present. Viability depends on the differential cost of purchased electricity and natural gas, and on the value placed on highly reliable, high-quality power for specific applications. Other applications require advancements in fuel cell technology to be considered economically viable. Cogeneration thermal-recovery opportunities at central boiler plants and premium power-generation requirements will often dictate the need for multiple fuel cell power plants at the same site. The ability for multiple fuel cell power plants to electric-load share is not available at this time. A master control system must be developed to synchronize the individual fuel cell power plants for this purpose.

Security requirements demand that backup power supply systems be capable of operating on logistics fuels. To date, the commercially available PC25 PAFC has been shown to be capable of operating on natural gas, propane, landfill gas, and anaerobic digester gas. Alternative logistics-fuel capability (e.g., JP8, Jet A, kerosene, diesel fuel, etc.) and on-line automatic fuel-switching capability are required for widespread DOD application. Fuel cell power plants have significantly lower operation and maintenance cost than other distributed-generation technologies, but they have significantly higher initial capital cost at present. Reducing the initial capital cost of fuel cell power plants would greatly increase their economically viable application within DOD.

4.3.2 Mobile

The high efficiency, quiet operation, and negligible pollutant emissions from fuel cells combine to make this a highly promising technology, both for land-based and sea-based DOD mobile power applications. Both require the ability to reform diesel fuel into hydrogen gas. A number of efforts are underway within the industrial sector to develop this ability. These efforts are initially concentrating on low power-generation levels, with scale-up to greater levels to follow. As a result, land-based mobility applications, with their lower power requirements, are likely to be the first area in which DOD will benefit. The higher power requirements of ship service power/main propulsion must await further advancements in this field. Additionally, sea-based mobility applications will require that existing fuel cell technology be adapted for the marine environment.

4.3.3 Other Uses

Increasing destabilization in many regions of the world poses an imminent threat to vital U.S. interests, requiring rapid response and "light, lean, and lethal" force deployments. As illustrated by the Gulf War, the United States must be increasingly prepared to rapidly deploy intervention forces, and to sustain them indefinitely. However, coupled with overseas base reductions, DOD must now rely almost exclusively on mobile, air-deployable infrastructure to stage and support U.S. air and land operations in many remote locations.

Mobile Electric Power (MEP) is one of five essential infrastructure elements in Tri-Service deployments. The Army Force Providers and the Air Force Bare Bases are examples of Tri-Service extensive use of MEP generators. The rapid evolution of fuel cell technology as a replacement for conventional electric power generators has provided a gateway to future power systems using hydrogen as the primary fuel. Fuel cells, with their high cycle efficiencies (exceeding 60%) and operation simplicity, afford high reliability and efficient use of primary energy in the form of hydrogen. The major drawback to militarizing the use of fuel cells has been the inability to effectively use battlefield fuels as the primary energy source. The ability to reform battlefield fuels into hydrogen would provide higher power-generation system efficiency, lower emissions, a lower infrared signature, and lower noise.

The Air Force, in particular, has standardized its battlefield energy on logistic fuels, especially JP-8. The ability to use logistic fuels in fuel cells would provide the military the ability to use this new and important technology and to provide further impetus for fuel cell development. The fuel cell generator system will provide efficient, reliable, and environmentally safe power to bare-base and Air Expeditionary Force (AEF) operations.

Fuel cell technology also holds promise in the replacement/augmentation of existing battery packs for individual-soldier use. Using portable fuel cells to power in-field communication equipment, sensor suites, and battery chargers would result in weight-savings and a longer lifetime over the current use of batteries. Again, the primary technical challenge facing this application is identification of an appropriate hydrogen source for the fuel cell.

5.0 Emissions

5.1 General

In the United states, fossil-fueled electric utilities account for two-thirds of the sulfur dioxide (SO_2), one-third of the nitrogen dioxide (NO_2), and one-third of the carbon dioxide (CO_2) emissions. Because of their electrochemical nature, fuel cell power plants are cleaner and more efficient than their combustion-based counterparts. Priority air emissions from fuel cells are so low that several U.S. Air Quality Management Districts have exempted them from operating permits. The high electrical conversion efficiency of fuel cell power plants means reduced CO_2 as well. Thus, fuel cell power plants can be of assistance in making DOD compliant with National and local air-emission standards and regulations.

A case in point is Vandenberg Air Force Base in California. In 1988, the Santa Barbara Air Pollution Control District (SBAPCD) cited Vandenberg AFB with five counts of violation, totaling $589,000 in fines, for emissions emanating from their diesel-fueled turbine exhaust stacks. The Air Force negotiated a quid pro quo settlement with the SBAPCD in lieu of paying the fines, the parties agreed that Vandenburg would test a fuel cell over several years, using varying load configurations. This fuel cell was the first installed in the FY93 Natural Gas Utilization Equipment program.

The following sections provide fuel cell emission performance specifications, as claimed by industry and as measured by independent emission-test programs, and an estimate of the emissions reduction that fuel cell power plants can provide to DOD.

5.2 Fuel Cell Performance Specifications (Industry)

The Federal standard for fuel cell performance, *New Source Pollution Standard (NSPS) for Existing Boilers, New Boilers, and New Combined Cycle Gas Turbines (CCGT)*, is shown in Table 2. ONSI Corporation conducted factory production emission tests of sixteen Model PC25A fuel cell power plants in 1992 to develop “fleet average” data, also shown in Table 2. These fleet-average measurements are the basis for graphical comparisons of the PC25A fuel cell power plant to the Federal standard that appear in ONSI’s literature (Table 2).[8]

ONSI chose to quote emission levels that were higher than the factory test-fleet averages in their Product Description brochure. This was done to allow themselves a margin of safety due to variations in the measured values among the sixteen factory-tested power plants, and recognizing that emissions from field-installed power plants may differ from factory test results due to operational parameters and local ambient concentrations of criteria pollutants.[9] While the typical emission levels from ONSI’s literature[10] reflect results from the Model PC25A fuel cell power plant, ONSI claims that they would be typical of the Model PC25B and Model PC25C fuel cell power plants as well.

5.3 Fuel Cell Performance Specifications (Independent Results)

In 1992, the South Coast Air Quality Management District (SCAQMD) conducted independent emission testing of an ONSI Model PC25A fuel cell power plant that had been installed at the SCAQMD facility in Diamond Bar, California. Table 2 shows SCAQMD's limits and the results of their measurements. As a result of these tests, SCAQMD granted natural gas fuel cells a blanket exemption from all air-quality permitting requirements in the Los Angeles Basin Area.

In 1996 and 1997, emissions tests were conducted on three ONSI Model PC25B fuel cell power plants purchased from the FY93 Congressional Appropriations as part of the DOD Fuel Cell Demonstration Program. These fuel cell power plants are located at the Naval Hospital, MCAGCC Twentynine Palms, in Twentynine Palms, California, Kirtland AFB in Albuquerque, NM, and Fort Eustis in Newport News, VA. Results of these tests are shown in Table 2. No independent emission testing has been performed on ONSI Model PC25C fuel cell power plants.

All of the independent emission test results of ONSI fuel cell power plants can be seen to be less than the "typical" emission levels published in the ONSI literature. As a result, the published "typical" emission level values may be used with confidence to provide conservative estimates of fuel cell emission reduction potential.

Table 2. Summary of Fuel Cell Air Emissions Data

Data Source	NO_x	CO	NMHC*	SO_x	Particulates
Federal New Source Pollution Standard (NSPS)					
Existing Boilers	55	17	1.0	N/A	N/A
New Boilers	13	3.4	0.7	N/A	N/A
New Combined Cycle Gas Turbines (CCGT)	7.5	9.7	6.6	N/A	N/A
Industry Data (ONSI)					
Measured, PC25A Fleet Average	0.46	1.1	0.03	Negligible	Negligible
Literature, PC25 Typical Values	1	5	1	Negligible	Negligible
Independent Measurements					
SCAQMD limits	3	10	250	N/A	N/A
SCAQMD measured, PC25A Power Plant	0.045	1.40	0.03	Negligible	Negligible
Naval Hospital, MCAGCC Twentynine Palms, CA	0.59	0.54	0.74	Negligible	Negligible
Kirtland AFB, Albuquerque, NM	0.68	2.14	0.78	Negligible	Negligible
Fort Eustis, Newport News, VA	0.65	4.37	0.23	Negligible	Negligible

All units are ppmv (parts per million by volume), 15% O_2, dry.
*NMHC – non-methane hydrocarbons

5.4 Projected DOD Fuel Cell Emission Reduction

Estimates have been made of emission reductions for the DOD fleet of thirty ONSI Model PC25 fuel cell power plants purchased as a result of the FY93–94 Natural Gas Utilization Program. These estimates are based upon monitoring of the fleet's total operational hours, total electrical and thermal output levels, and an emission rate factor for each site that reflects the mix of utility power generation sources typical of the geographic region in which the fuel cell power plant is located.

The emission rate factors were obtained from the DOD Renewables and Energy Efficiency Planning (REEP) computer program, which provides these factors state-by-state from data published by the Energy Information Administration in the February 1993 issue of their *Electric Power Monthly*. As of January 1, 1998, the DOD fleet had cumulatively produced 35,967 MWH of electricity and 46,000 MBtus of thermal energy, while abating 161 tons of SO_x, 74 tons of NO_x, and 6 tons of CO. Greenhouse gas emissions can also be reduced through the use of fuel cell power plants because of their higher overall efficiencies. Based on average measured emissions from the three DOD Model PC25B power plants on which testing was performed, and using emission rate factors obtained from REEP, it is estimated that the DOD fleet of thirty fuel cell power plants has cumulatively reduced CO_2 emissions by 8,356 tons.

6.0 Funding

Funding for development and commercialization of fuel cell technology historically has been a mix of Federal and private-industry resources. The phosphoric acid fuel cell (PAFC) is the most advanced fuel cell technology, and is the only one commercially available at present (ONSI Corporation Model PC25C). Section 6.1 describes DOD, DOE, and industry funding to support PAFC-development activities through FY97. Section 6.2 details the DOD, DOE, and industry strategy for executing the FY98 Congressionally identified funds for PAFCs. The Service and Defense Agency budget request for FY98 included no funding for fuel cell technology.

6.1 Prior-Year Funds for PAFC

Development and commercialization of ONSI Corporation's Model PC25C PAFC was funded by DOD, DOE, International Fuel Cells Corporation (IFC), and a consortium of gas and electric utilities and utility-support organizations, including the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI). It should be noted that each of these participants describes its prior-year funds contribution in terms most recognizable and applicable to their respective planning and budget processes.

DOE's funding categories are Research, Development, Demonstration, and Commercialization. International Fuel Cells and the utility consortium use the funding categories of Research, Development, Prototyping, Demonstration, Commercialization, and Product Enhancement.[11]

DOE provided approximately $292M for PAFC technology during FY76–92, the approximate time during which PAFC became commercially available. This funding was allocated into the Research and Development categories. The utility consortium, as noted above, spent $250M in the categories of Research, Development, Prototyping, and Demonstration during the same approximate timeframe.

International Fuel Cells (IFC) expended $300M in the categories of Research, Development, Prototyping, Demonstration, and Commercialization through calendar year 1994 for development and commercialization of the PAFC Model PC25A. IFC spent an additional $100M in Product Enhancement during 1995–1997, involving development of PAFC Models PC25B and PC25C.[12]

DOD provided $35.8M through the Natural Gas Utilization Equipment Program (FY93–94) and $18.6M through the Climate Change Fuel Cell Program (FY95–97), both in the category of Demonstration and Validation funds. In addition, $1.25M was provided through DARPA's Fuel Cell Technology Program in the category of Exploratory Development. Detailed discussion of DOD RDT&E funding categories is provided in Appendix C.

6.2 FY 1998 Investment Strategy

With the development of this report, the Service Components, Defense Agencies, and DOE undertook a rigorous review of the prior years' funding activities, programs, and general focus areas for development and demonstration of fuel cell technology. This information is detailed in Chapters 2, 3, and 5, and forms the basis for continuing a compatible and common DOD and DOE strategy for executing the current-year appropriations.

FY98 funds for continuing PAFC development and demonstration activities were provided by the Congress in Army budget accounts Program Element (PE) 0605856A — Environmental Compliance, and PE 0602784A — Military Engineering. The amount of this funding is $5M and $7.5M, respectively. Similarly, the Congress added $1.75M in Navy budget account PE 0603712N — Environmental Quality and Logistics to establish cooperative R&D between the Naval Surface Warfare Center (NSWC) in Crane, Indiana and private industry. The focus for the Navy funds is the demonstration of a 250-kW proton-exchange membrane (PEM) fuel cell. Details of this effort have already been outlined in Section 3.2.3.

DOD will partner with DOE/FETC to continue a Federal grant program for the purchase and installation of PAFC power plants. Funds for this $5M program will be provided from the Army's Environmental PE (as noted above) and will continue the purchase of 200-kW PAFC power plants. DOD and DOE/FETC have agreed to continue the prioritization for DOD installations when developing this program. This strategy remains consistent with prior-year investments to reduce the initial capital cost for fuel cells by increasing production and to derive the benefit for economies of scale during production. DOD will not budget future-year funds for continuing a Federal Grant program for fuel cell development.

The remaining $7.5M will be jointly executed by the Services, the National Defense Center for Environmental Excellence (NDCEE) in Johnstown, PA, and industry. The Services include the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL) in Champaign, IL; the Armament Research, Development, and Engineering Center (ARDEC) in Picatinny, NJ; and the Air Force Research Laboratory at Tyndall AFB, FL. The overall strategy for these funds will be (1) to continue the fuel cell activities that increase DOD's ability to more efficiently construct, operate, and maintain its installations, while ensuring environmental quality and safety at a reduced life-cycle cost, and (2) to accelerate the use of fuel cell technology for future military deployment and in-theater operations. This program will have seven general thrusts, described briefly as follows:

Task 1 — CERL will purchase a 200-kW fuel cell power plant for installation at the NDCEE. CERL, in cooperation with ARDEC and industry, will derive a plan to support verification testing of improved components, to be performed by the NDCEE.

Task 2 — CERL and the Air Force Research Laboratory will study the use of logistics fuels like JP-8 in fuel cells. The military has standardized its fuel energy requirements on logistics fuels and this work will assess the use of a logistics fuel reformer (LFR) suitable for mobility operations, perhaps making it a key component of future deployable fuel cell generator systems.

Tasks 3 through 7 — CERL and industry will develop separate detailed tasks around Cell Stack Assembly Product Enhancement, Fuel Cell Processor Subsystem Product Enhancement, Power Conditioner Subsystem Enhancement, Module Product Enhancement, and related verification and testing efforts. These tasks will focus specifically on reducing the power plant's life-cycle cost or on expanding its operating characteristics.

Industry's contribution to this plan will, at a minimum, equal Federal funding for each task.

7.0 Summary

DOD, DOE, industry, and others have worked together to develop and demonstrate the utility and value of fuel cell technology. This technology offers an attractive alternative for power generation, due to its ultrahigh energy-conversion efficiency and extremely low environmental emission. Fuel cells can be used for a wide variety of power-plant applications, using a variety of fuels, and provides a range of power generation from kilowatts to hundreds of megawatts.

However, it is likely that the primary application for fuel cells in the foreseeable future will be distributed-generation (DG) technology. DG technologies, including fuel cells, require more development at this time. The major drawback to widespread acceptance of fuel cells is the technology's relatively large initial capital cost in comparison to other electric-generation technologies. It has been estimated that a 50% reduction in initial capital cost will be required to make fuel cell technology economically viable for broad use. This cost reduction can be brought about by increased production, which takes advantage of economies of scale, and by R&D efforts that lead to lower cost for individual components.

DOD and DOE have worked together to plan tasks in response to these challenges as a part of an overall federal government and industry strategy for best use of FY 1998 funds. DOD will continue to utilize a portion of these funds to further exploit the potential use of this technology in military unique operations and processes. Further, the FY 1998 strategy continues production of PAFC fuel cells as a part of the overall federal government strategy to provide industry incentive for their pursuit in developing new and innovative systems and components that may further reduce the initial capital cost of fuel cells. Lastly, DOD, DOE, industry, and others will continue to be active partners in fuel cell forums and demonstrations in order to increase technology transfer opportunities among these entities and to further focus upon the objective to increase the broad acceptance of fuel cells.

8.0 Bibliography

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9.0 Appendices

A. DOD Fuel Cell Locations

B. Non-DOD Fuel Cell Locations

C. DOD Funding Categories Description

D. Energy and Fuel Cell Web Sites

E. References

Appendix A

DOD Fuel Cell Locations

FY93–94 Program

ARMY SITES

1. Ft. Richardson, Anchorage, AK
2. Pine Bluff Arsenal, White Hall, AR
3. Ft. Huachuca, Sierra Vista, AZ
4. U.S. Army Soldier Systems Command, Natick, MA
5. Picatinny Arsenal, Dover, NJ
6. U.S. Military Academy, West Point, NY
7. Watervliet Arsenal, Albany, NY
8. Ft. Bliss, El Paso, TX
9. Ft. Eustis, Newport News, VA

NAVY/MARINE SITES

10. CBC Port Hueneme, Port Hueneme, CA
11. Naval Hospital–MCAGCC Twentynine Palms, CA
12. Naval Hospital–MCB Camp Pendleton, Oceanside, CA
13. Subase New London, Groton, CT
14. Naval Hospital–NAS Jacksonville, Jacksonville, FL
15. U.S. Naval Academy, Annapolis, MD
16. Naval Oceanographic Office, John C. Stennis Space Center, MS
17. NAS Fallon, Fallon, NV
18. Naval Education Training Center, Newport, RI

AIR FORCE SITES

19. Little Rock AFB, Jacksonville, AR
20. Davis-Monthan AFB, Tucson, AZ
21. Edwards AFB, CA
22. Vandenberg AFB, Lompoc, CA
23. Barksdale AFB, Bossier City, LA
24. Westover AFB, Chicopee, MA
25. 934th Airlift Wing, Minneapolis, MN
26. Kirtland AFB, Albuquerque, NM
27. Nellis AFB, Las Vegas, NV
28. 911th Airlift Wing, Pittsburgh, PA
29. Laughlin AFB, Del Rio, TX

OTHER DOD SITES

30. National Defense Center for Environmental Excellence, Johnstown, PA

FY95 Program

1. Fort Richardson, Anchorage, AK
2. Sigonelli Naval Air Station, Sicily (4)

FY96–97 Program

ARMY SITES

1. Fort Richardson, AK (2)
2. Fort Gordon Army Base, GA (2)

NAVY/MARINE SITES

3. Naval Construction Battalion Center, MS

AIR FORCE SITES

4. McGuire Air Force Base, NJ

Appendix B

Non-DOD Fuel Cell Locations

FY93–94 Program
None

FY95 Program
1. National Rural Electric Cooperative (to be moved to multiple sites), GA, CO, AK
2. City of Mesa, Mesa, AZ
3. City of Pittsburg, Pittsburg, CA (2)
4. Sacramento Municipal Utility District, Sacramento, CA
5. Connecticut Natural Gas Corp, Hartford, CT
6. United Technologies Corp., Windsor Locks, CT
7. State of Connecticut, CT (2)
8. Braintree Electric Light Department, Braintree, MA
9. New England Power Service, Winthrop, MA
10. Alcorn State University, Lorman, MS
11. Jersey Central Power and Light, Murray Hill, NJ
12. Brooklyn Union Gas Co., Staten Island, NY (2)
13. Onondaga-Courtland-Madison, Syracuse, NY
14. New York Power Authority, Yonkers, NY (4)
15. Washington Water Power, Spokane, WA
16. Equitable Resources, TBD
17. Equitable Resources, TBD
18. Equitable Resources, TBD
19. Equitable Resources, TBD
20. Equitable Resources, TBD
21. Equitable Resources, TBD
22. CLC Srl. (Italy), Halle, Germany
23. CLC Srl. Piazza Carignano (Italy), Hamburg, Germany
24. CLC Srl. (Italy), Nuremberg, Germany
25. CLC Srl. (Italy), Oranlenburg, Germany
26. CLC Srl. (Italy), Ansaldo, Saarbrucken, Germany
27. Toshiba Corporation, Fuchu-Shl, Tokyo, Japan
28. Toshiba Corporation, Kelhin, Yokohama, Japan
29. Toshiba Corporation, NEL, Yokohama, Japan
30. CLC Srl. (Italy) , Ansaldo, Varberg, Sweden

FY96–97 Program

1. Rancho Las Virgines Composting Facility, Calabasas, CA (2)
2. Kaiser Permanente Hospital, Fontana, CA (3)
3. St. John's Regional Medical Center, Oxnard, CA
4. Kaiser Permanente Hospital, Pasadena, CA (2)
5. Sacramento Municipal Utility District (computer facility), Sacramento, CA (2)
6. Sacramento Municipal Utility District (hospital), Sacramento, CA (2)
7. Santa Clara University, Santa Clara, CA (2)
8. Hill Canyon Wastewater Treatment Plant, Thousand Oaks, CA (2)
9. Danbury City Landfill, Danbury, CT (2)
10. Science Center of Connecticut, East Hartford, CT
11. Northern Capitol Landfill Regional Disposal Facility, East Windsor, CT
12. Greenwich Hotel, Greenwich, CT
13. Hartford Hospital, Hartford, CT (6)
14. Hartford City Landfill, Hartford, CT (4)
15. Yankee Gas Services Corporate HQ, Meriden, CT
16. Norwalk Hospital, Norwalk, CT (2)
17. Locite Corporation, Rocky Hill, CT (3)
18. CTG Liquid Natural Gas Plant, Rocky Hill, CT
19. Waste Paper Collection Site, Willimantic, CT
20. Louisiana Gas Services Main Office Complex, Harvey, LA
21. 4 Times Square Corporation, New York City, NY (2)
22. Columbia Boulevard Wastewater Treatment Plant, Portland, OR
23. Veteran's Medical Center, Charleston, SC (2)
24. James Quillian Veteran's Hospital, Johnson City, TN (2)
25. Toshiba Corporation, Houston, TX

Appendix C

DOD Funding Categories Description

Budget Activity 1 — Basic Research

Basic Research provides fundamental knowledge for the solution of identified military problems. It includes all effort of scientific study and experimentation directed toward increasing knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term National security needs. It provides farsighted, high-payroll research, including critical enabling technologies that provide the basis for technological progress. It forms a part of the base for (a) subsequent exploratory and advanced developments in Defense-related technologies, and (b) new and improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion., mobility, guidance and control, navigation, energy conversion, materials and structures, and personnel support. Basic Research efforts precede the system-specific research described in DODD 5000.1.

Budget Activity 2 — Applied Research

This activity translates promising basic research into solutions for broadly defined military needs, short of major development projects, with a view to developing and evaluating technical feasibility. This type of effort may vary from fairly fundamental applied research to sophisticated breadboard hardware and study, programming and planning efforts that establish the initial feasibility and practically of proposed solutions to technological challenges. It thus includes studies, investigations, and development effort. The dominant characteristic of Applied Research is that it is directed toward specific military needs with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters. Program control of the Applied Research element will normally be exercised by general level of effort. Applied Research precedes the system-specific research described in DODD 5000.1.

Budget Activity 3 — Advanced Technology Development

Advanced Technology Development includes all efforts that have moved into the development and integration of hardware and other technology products for field experiments and tests. The results of this type of effort are proof of technological feasibility and assessment of operability and productivity that could lead to the development of hardware for service use. It also includes advanced-technology demonstrations that help expedite technology transition from the laboratory to operational use. Projects in this category have a direct relevance to identified military needs. Advanced Technology Development may include concept exploration as described in DODD 5000.1, but is non-system-specific (Milestone O).

Budget Activity 4 — Demonstration and Validation
Demonstration and Validation includes all efforts associated with advanced-technology development used to demonstrate the general military utility or cost-reduction potential of technology when applied to different types of military equipment or techniques. It includes evaluation and synthetic environment, prototypes, and proof-of-principle demonstrations in field exercises to evaluate system upgrades or provide new operational capabilities. The demonstrations evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost-reduction potential of advanced technology. It may include concept exploration as well as demonstration and validation as described in DODD 5000.1, but is system-specific (Milestone O/1).

Budget Activity 5 — Engineering and Manufacturing Development

Engineering and Manufacturing Development includes those projects that are in engineering and manufacturing development for Service use. This area is characterized by major line-item projects, and program control will be exercised through review of individual projects. This category includes engineering and manufacturing development projects as described in DODD 5000.1, and may include operational test and evaluation (Milestone 11).

Budget Activity 6 — RDT&E Management Support

RDT&E Management Support includes efforts directed toward support of RDT&E installations or operations required for use in general research and development (R&D) and not allocable to specific R&D missions. Included are technical integration efforts, technical information and activities, space programs, major test ranges, test facilities and general test instrumentation, target development, support of operational tests, international cooperative R&D, and other R&D support.

Budget Activity 7 — Operational Systems Development

Operational systems Development includes R&D effort directed toward development, engineering, and test of changes to fielded systems or systems already in procurement that alter the performance envelopes. This category may include operational test and evaluation costs. It also includes R&D support to miscellaneous operational efforts such as Manufacturing Technology, Communications Security Equipment, Horizontal Battlefield Digitization, Joint Biological Defense, Satellite Communication Ground Environment, various classified programs, etc. Program control will be exercised by review of individual projects.

Appendix D

Energy and Fuel Cell Web Sites

Climate Change Fuel Cell Program
http://www.pica.army.mil/orgs/eto/fuel_cell.html

Defense Reform Initiative
http://www.defenselink.mil/dodreform/

DOD Fuel Cell Demonstration Web Page
http://www.dodfuelcell.com

DOE Federal Energy Technology Center
http://www.fetc.doe.gov/

National Energy Policy
http://www.acq.osd.mil/energylink/policy.htm

NDCEE's DOD Fuel Cell Guidebook:
http://www.ndcee.ctc.com/pdfindex.htm

Sustainable Energy Strategy — Clean and Secure Energy For a Competitive Economy, July 1995, a precursor to EO 12902
http://www.hr.doe.gov/nepp/titlepg.html

Appendix E

References

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2. H.R. Rep. No. 103–254 — Report of the Committee on Appropriations accompanying H.R. 3116, September 22, 1993, page 102.
3. Conference Report H.R. 103–339, to accompany H.R. 3116, November 9, 1993.
4. HR Rep. No. 105–340.
5. Telephone conversation between Ms. Linda Terravoa, PM Wide Area Mines, U.S. Army ARDEC, and Mr. Garry Kosteck, Industrial Ecology Center, U.S. Army ARDEC, March 12, 1998.
6. Conference Report H.R. Rep. No. 103–339.
7. Draft FY97 Department of Energy policy for Federal Government Energy Management, subsection "Building for the 21st Century."
8. Communication with Joe Staniunas, ONSI.
9. Communication with Joe Staniunas, ONSI.
10. PC25™ Fuel Cell Product Description brochure, ONSI Corporation, 1996.
11. Communication with Murdo Smith, IFC.
12. Communication with Murdo Smith, IFC.